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THE TRANSMISSION OF NEUTRONS AND GAMMA-RAYS THROUGH AIR SLOTS. PART II. THE TRANSMISSION OF NEUTRONS THROUGH STRAIGHT SLOTS IN WATER

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THE TRANSMISSION OF NEUTRONS AND GAMMA-RAYS THROUGH AIR SLOTS

Part II

The Transmission of Neutrons Through Straight Slots in Water

Robert D. Schamberger
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1 September 1954

REACTOR DEPARTMENT

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Using the slot box described in Part I[1] and thermal neutron detectors, the thermal neutron flux in the water above the air slots was determined as a function of slot dimension. Traverses were made in the water in the slot length and thickness directions in an effort to characterize the radiations in terms of the slot dimension. A few checking runs were made with a lead-covered fast-neutron dosimeter. Data will be presented for the slot sizes given in Table I.

TABLE I

Dimensions of the Air Slots

Width W (inches)	Nominal Thickness T (inches)	Length L (inches)
34	0.125	12 24 48
	0.25	48
	0.50	12 24 48 72 96
	1.00	12 24 48
	1.5	24 48
	3.0	24 48 72
12	3.0	24 36 48 72

In an investigation such as this it would be desireable to take both fast and slow neutron data over the slots for the entire dimensional spectrum. However, a serious limitation is imposed by the gamma-ray fluxes present on the use of the only available fast neutron detector; i.e., a Hurst-type dosimeter. This restricts its use to the longer slots. It was decided, therefore, that thermal neutron detectors be employed over the entire range of slot dimensions and that some checks be made, when possible, with the fast neutron dosimeter. A good correlation should not be expected, a priori, for those regions throughout which the thermal neutron portion of the spectrum is not in equilibrium with the high energy part.

The combination of a thermal neutron detector and water thickness, D, makes an energy dependent detector which will give results more representative of a fast neutron detector when D is made large compared to the thermal neutron diffusion length. This indicates that one should use large D for good agreement with the dosimeter. A complication still exists for large D and short slots, however, when the slow fission counter is used, because the large gamma-ray fluxes present induce photofission which represents a spurious count rate. In the case of thin slots, where the flux transmitted through the air is comparable to that going through the water, the photofission count rate can be a serious problem, especially for large D.

(1) BNL-2019

In order to characterize the neutron transmission in terms of the thermal neutron counter measurements, one must select some reproducible parameter. For this purpose, one may express the excess flux detected along the slot centerline as a function of the slot dimensions keeping a constant water separation D between the aluminum slot box and counter.

Figure 1a shows traverses taken beyond a typical air slot 0.25 x 34 x 48 inches. The 1 inch x 6 inch BF_3 counter was aligned horizontally with its long axis parallel to the 34 inch dimension of the slot. The horizontal traverses in this case were taken at Z values of 54, 60, and 66 inches which correspond to D values of 1.5, 7.5 and 13.5 inches. One notices that the more water there is between detector and slot, the broader the curves become. Figure 1b shows a vertical traverse along the centerline of the air slot. The vertical traverses in general have an attenuation length of about 4 cm with D=1.5 inches and between 5 and 6 cm at D=7.5 inches. A summary of such flux plots for D=1.8 inches and 7.5 inches are shown in Figures 2 through 6.

The log plot of Figure 2 indicates that with D=1.8 inches, as one varies the slot thickness, T, and holds length constant, a family of straight parallel lines is generated. The net flux was determined by taking the difference between fluxes obtained with the slot filled with air and with lucite. Values obtained with thicknesses of the order of .125 inches are uncertain for reasons discussed in Part I.

The slope of the lines as plotted is two, indicating that the transmitted flux varies as the square of the slot thickness. This is the behavior predicted by a line-of-sight calculation which assumes that the water is opaque to neutrons and that the emergent flux is essentially integrated by the detector.

Figure 3 shows a similar summary except that D=7.5 inches. Again the data are consistent with straight lines drawn with slope 2.0 to 2.1. Checks made with a lead-covered fast-neutron dosimeter and slots 48 inches in length and 0.50 inches and 2 inches thick give the 1.96 power for the thickness dependence.

The flux data, when plotted as a function of slot length, with thickness as a parameter, yield Figure 4 in which D=1.8 inches. The lines, as drawn, have slopes of minus 2 and are seen to fit the data fairly well indicating an inverse square length dependence. Similar results, shown in Figure 5, are obtained with D=7.5 inches.

This result is surprising for short lengths for which one expects deviations from inverse square dependence. In the experiment one must recall that the 40 inch source plate is 10.6 inches below the water tank bottom which in turn is separated by 3 inches of water from the slot bottom. As one decreases the slot length the detector "sees past" the aperture formed by the slot bottom and "looks at" a larger portion of the source plate. For lengths shorter than about 6.5 feet the detector can see past the edge of the source plate in the width direction, and hence the effective source size stays constant in this

direction. In the thickness direction the detector always looks at the source plate. If one calculates the solid angle subtended at the detector by the effective region of the source plate, then significant departures from inverse square law occur for slot lengths over most of the range studied. In the actual case, neutrons which must travel an oblique path from the source plate to detector are attenuated in the 3 inch thick water layer more than those which travel along the minimum length. This would tend to make an even greater inverse square behavior. There is some evidence that relatively smaller flux is obtained with shorter lengths as may be seen in Figure 5. The departure from geometrical behavior may be the result of an appreciable contribution to the flux getting out of the top of the slot by neutrons which come in the side of the slot near the bottom. In addition, a possible clue to the reason of the departures may be found in the rapid decrease in the flux in the water along the sides of the slot, which follows an inverse fourth power dependence on the length[2].

In one set of runs, the length dependence was studied using slots of width 12 inches and of thickness 3 inches. The source plate always filled the aperture formed by the slot bottom for the range of lengths 2 feet to 6 feet which were employed. In Figure 6 are shown the results obtained with D = 1.5, 7.5, 13.5, and 19.5 inches. For D = 1.5 inches, the slope with L greater than 2 feet is about 2.9. For the other D values the slope is close to 2.0. This result is markedly different for the slower neutron component of the emergent flux which was obtained at D = 1.8 inches for the 34 inch width, but it is the same as that obtained earlier for the fast neutron component. At least some of the difference with the small D is the result of the change in geometry.

Comments on the data:

The data presented in the form of graphs in Figures 7 through 25. At the upper right hand corner of each figure is a description of the experimental conditions which follow the code outlined in Part I of this series[1]. For those instances in which an appreciable photofission count rate was obtained with the fission counter, a correction was applied. In the case of vertical traverses the correction usually was appreciable in the region where the operational range of the BF_3 counter overlapped that of the fission counter. For the horizontal traverses, the correction became more serious as the detector was moved away from the slot centerline. Fission counter data which have been corrected for photofissions appear as parts of dashed curves. For example, in Figure 10 run number 2163 has been corrected for gamma-ray effects for x values greater than 7.5 inches.

An estimate of the size of the photofission background can be made from Figure 11 in which background run 2538 taken with the fission counter should be compared with run 1645 obtained with an aluminum walled

[1] BNL - 2019

[2] See Part IX, BNL - 2027

ionization chamber. Run 1645 has been arbitrarily normalized to run 2538. It is seen that the "background" detected in 2538 was mainly gamma-rays. The true neutron background, obtained with a BF_3 counter, is given by run 2590A. The companion horizontal traverses are indicated in Figure 12 in which run 1385, obtained with the fission counter, is to be compared with run 2590 for which a BF_3 counter was used.

Inexplicable changes in overall response seemed to have occurred in several instances, as for example runs 1736 and 1931 of Figure 17 or those of Figures 22 and 23. Since, in some of these instances, periods of time of a few months intervened between runs, it is difficult to ascribe the variations to any single factor.

Summary of results:

1. The peak neutron flux in water above a slot whose thickness is not great compared to the counter size follows a thickness square dependence. This result seems to be independent of the energy of the neutrons

2. The measured length dependence for the slower neutron component is an inverse square, and for the faster component it is about the same. This dependence is not expected for the case investigated in which the slot width was comparable to the source size. This suggests, at least for the lower energy component, that some mechanism other than line-of-sight transmission makes important contributions to the emitted flux.

3. When the slot width was small compared to source size the length dependence for the faster neutrons was the inverse square.

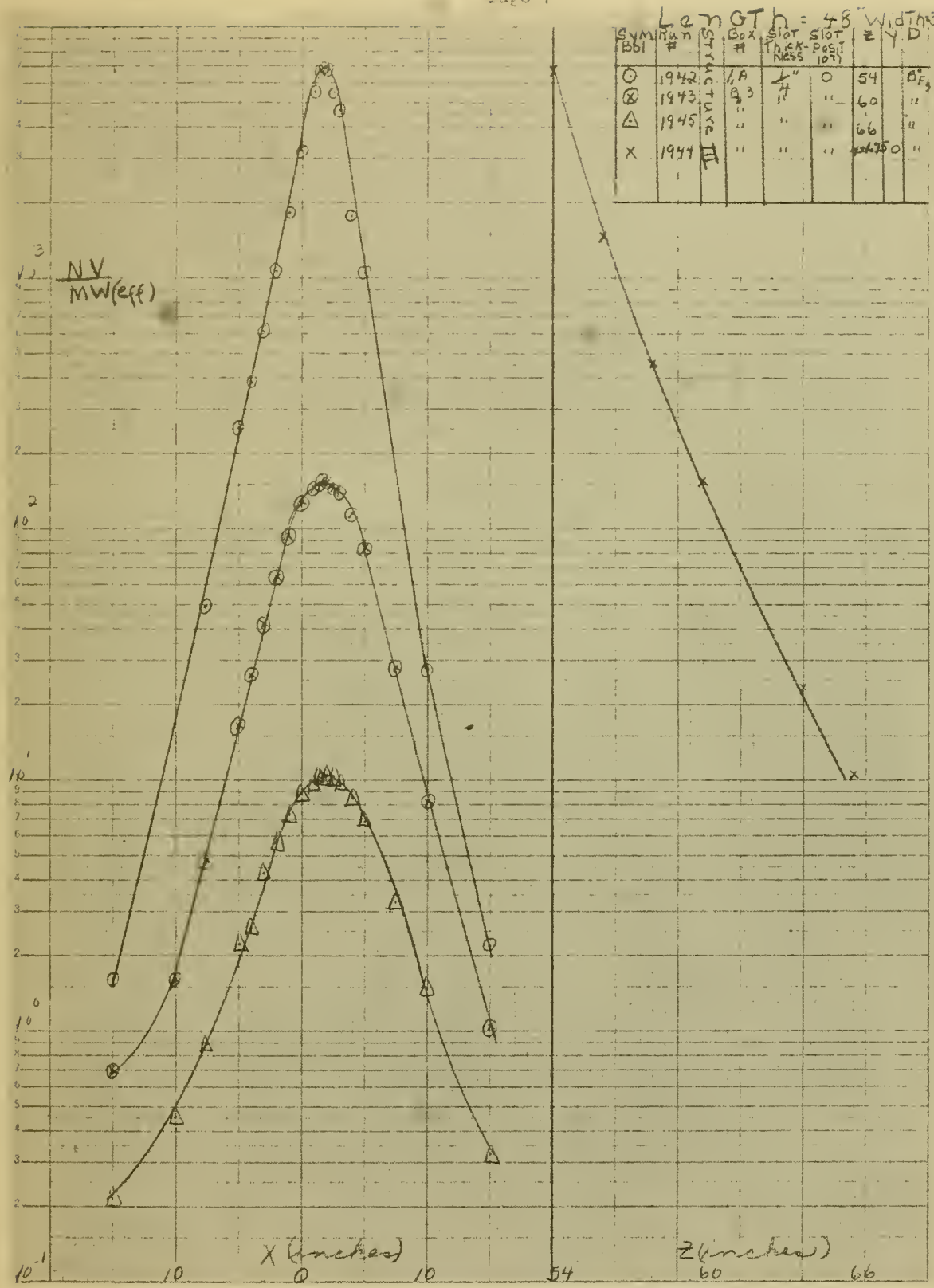

Length = 48" Width = 7"
Symbol | Run # | Structure | Box # | Slot Thickness | Slot Position | Z | Y D
⊙ | 1942 | I | 1/A | 1/4" | 0 | 54 | BF3
⊗ | 1943 | | B3 | " | " | 60 | "
△ | 1945 | | " | " | " | 66 | "
X | 1944 | | " | " | " | 72 | "
NV / MW(eff)
X (inches)
Z (inches)

FIG. 1a

FIG. 1b

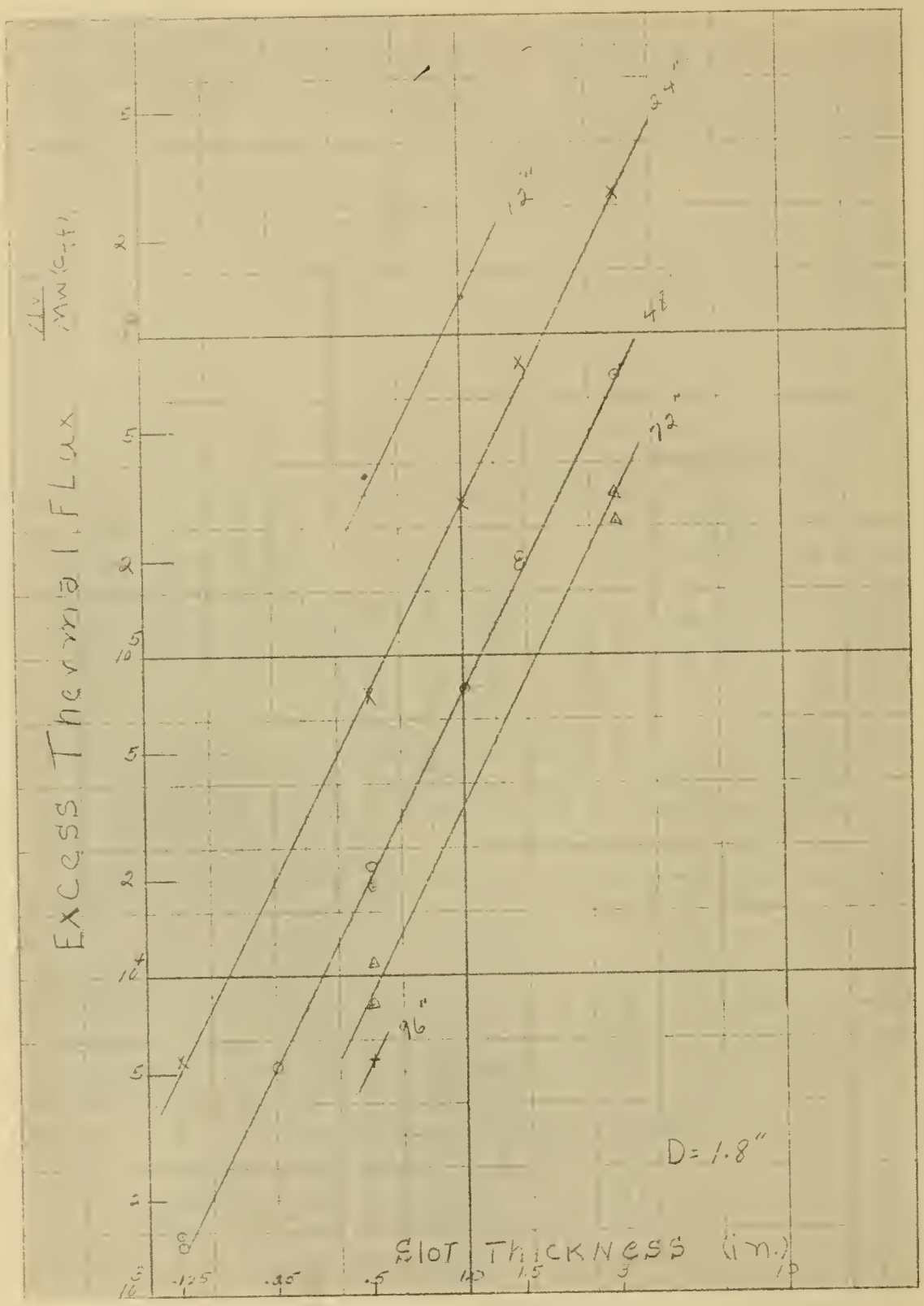
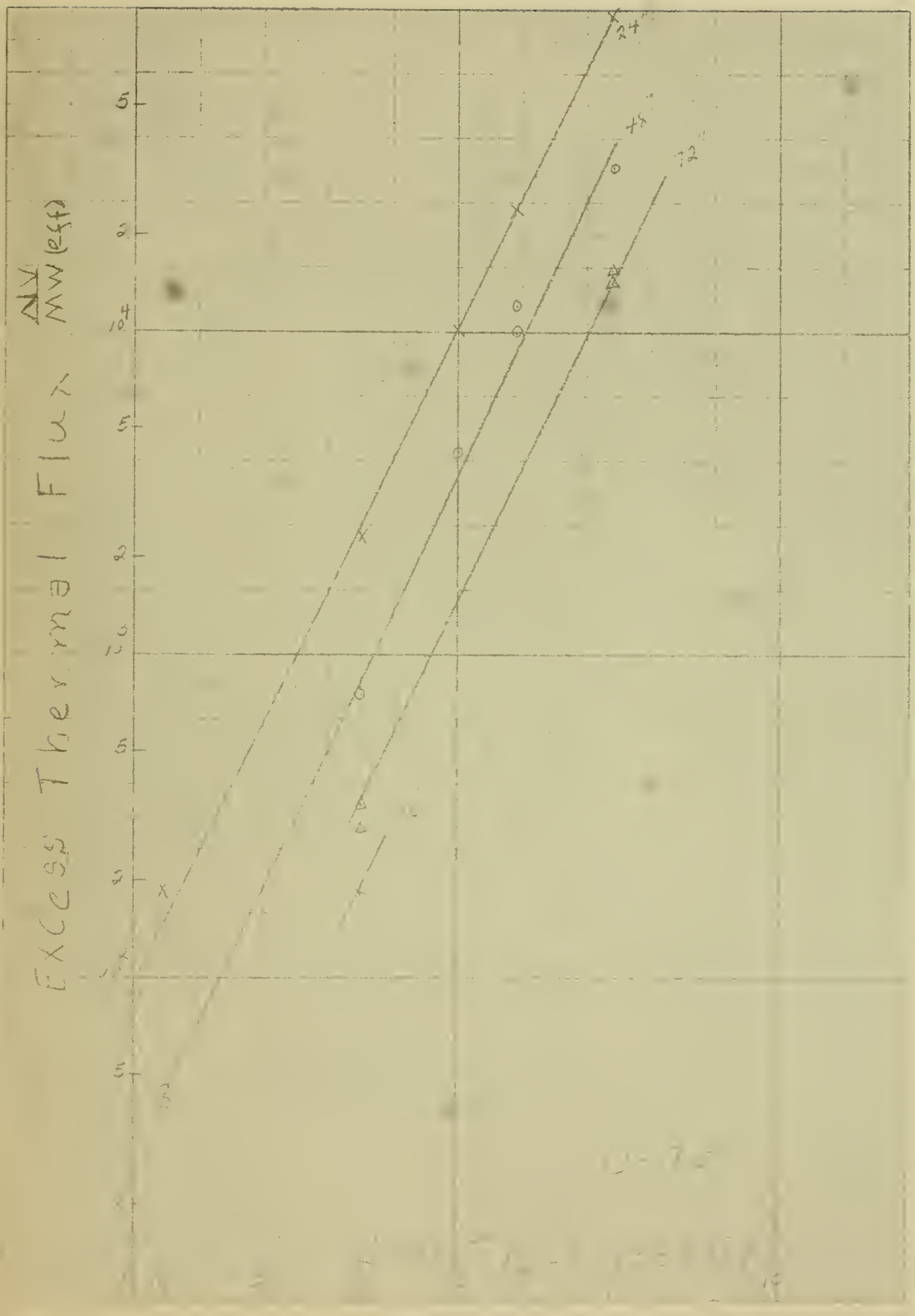

Excess Thermal Flux
Slot Thickness (in.)
D= 1.8"
12"
24"
48"
72"
96"
.125
.25
.5
1.0
1.5
3
10

FIG. 2


Excess Thermal Flux $\frac{\Delta V}{MW(eff)}$
24"
48"
72"
5
2
10^4
5
2
5
2
5

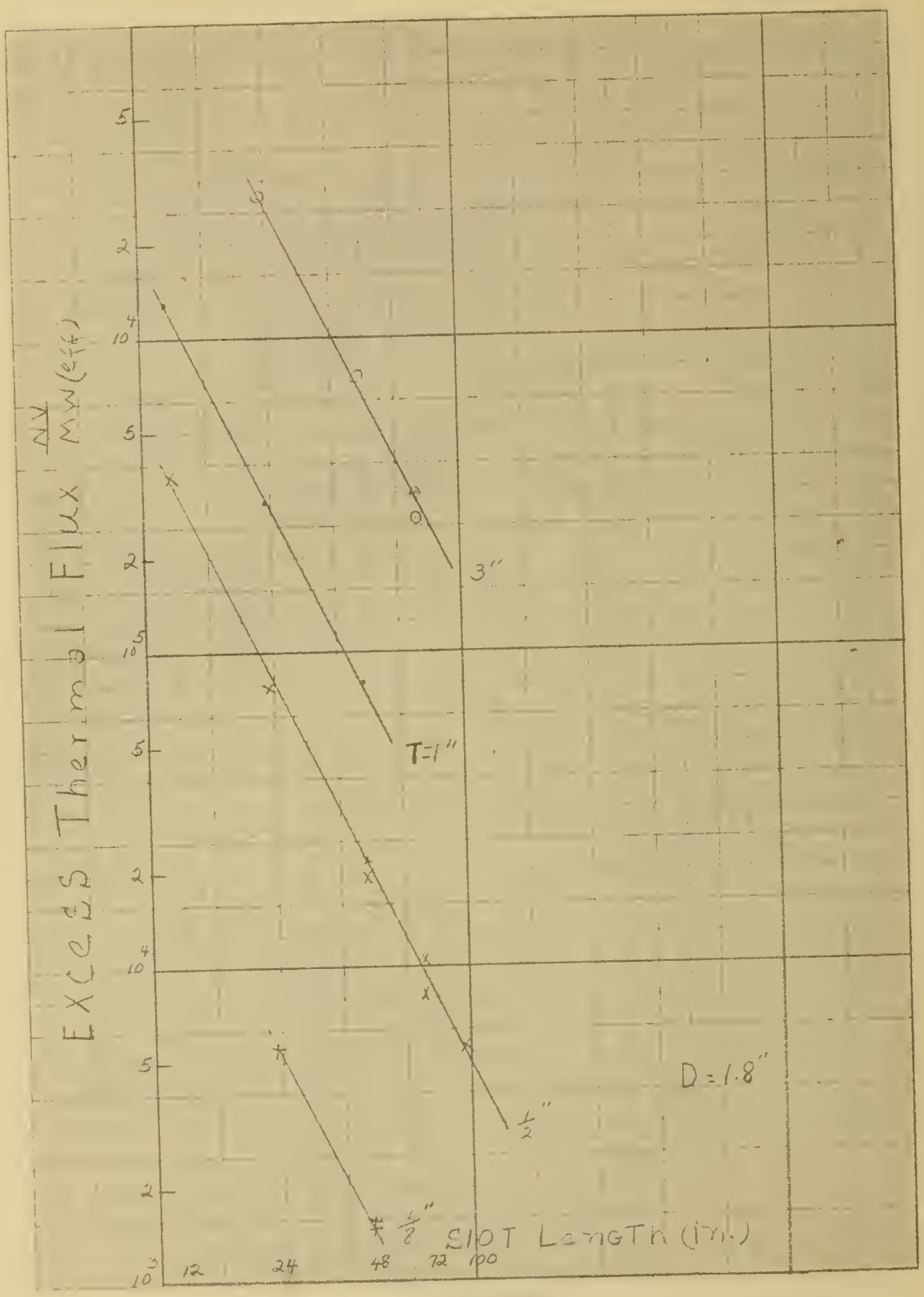

EXCESS Thermal FLUX $\frac{\Delta V}{MW(eff)}$
10^4
5
2
10^5
5
2
10^4
5
2
10^3
12
24
48
72
100
3"
T=1"
$\frac{1}{2}$"
D=1.8"
$\frac{1}{8}$" SLOT LENGTH (in.)

FIG. 4

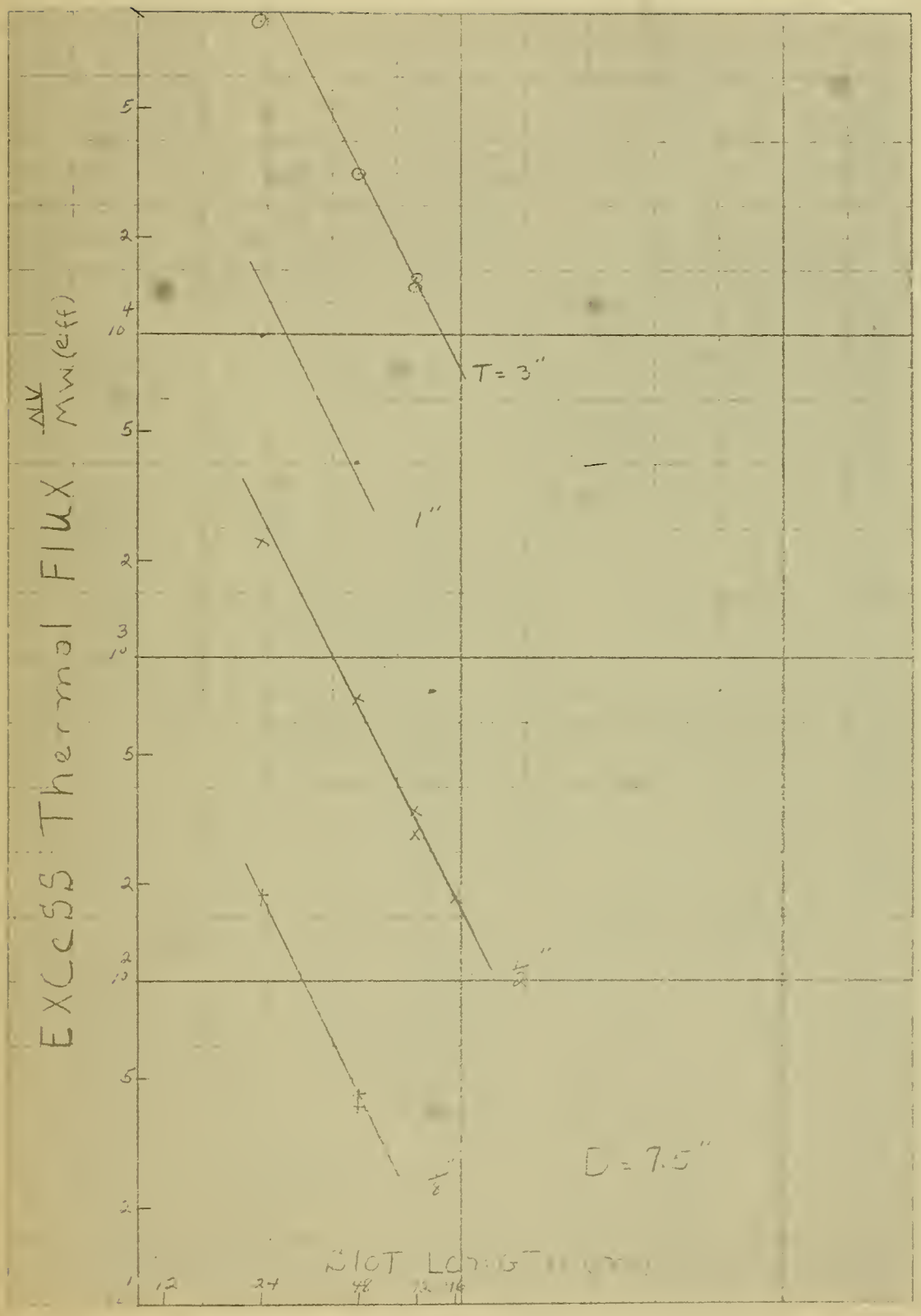


Fig. 5

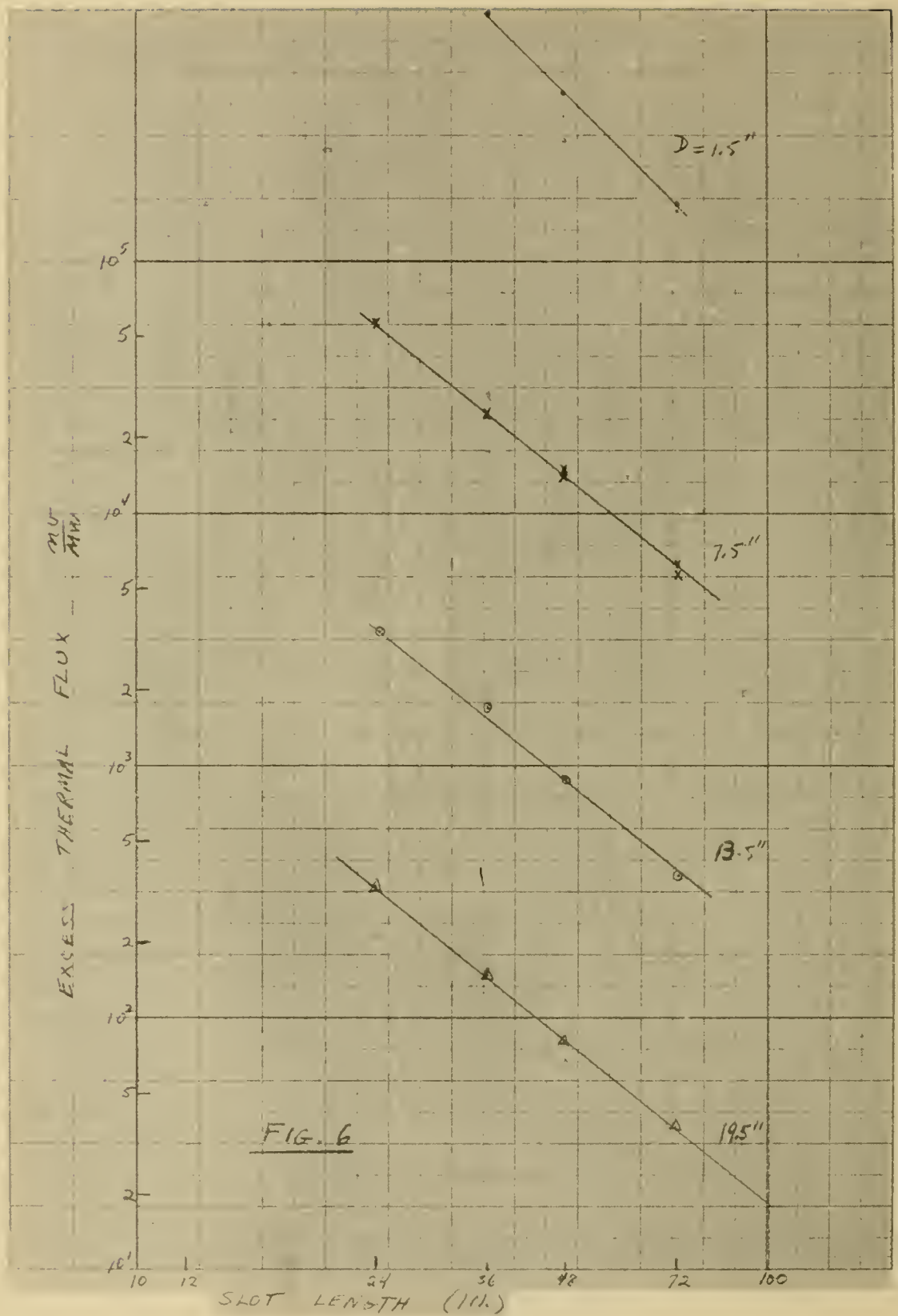

D = 1.5"
7.5"
13.5"
19.5"
EXCESS THERMAL FLUX — mv/MW
SLOT LENGTH (in.)
10
12
24
36
48
72
100

FIG. 6

Length = 12" Width = 34

Sym Bol	Run #	Structure	Box #	Slot Thickness	Slot Position	X	Y	D
⊙	1374	III	1	0	0	1.936	0.64	Fission-a
⊗	1409	"	"	1/2"	"	2	0	"
△	1391	"	"	1"	"	1.5	"	"

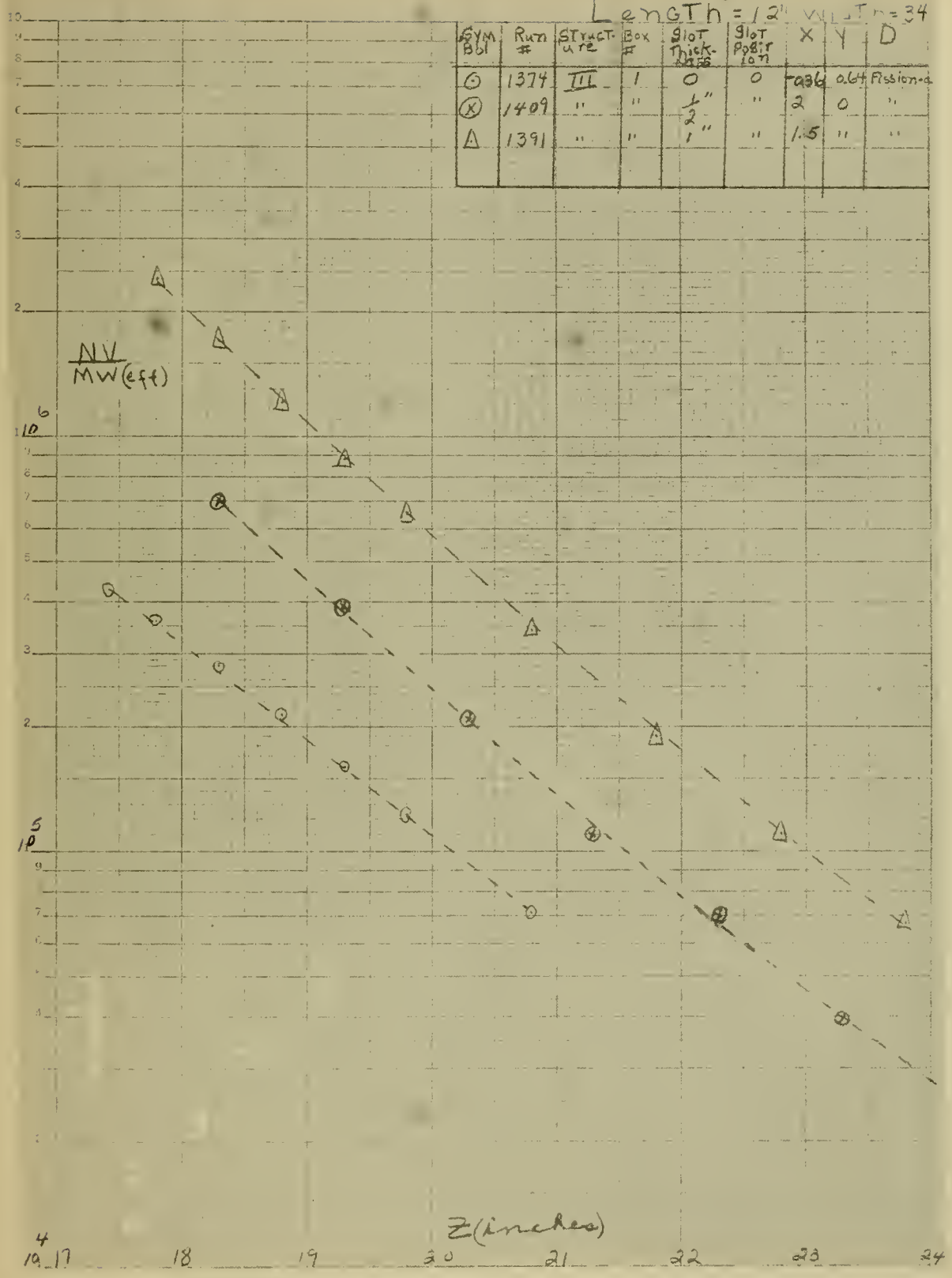


FIG 7

Length = 12" Width = 2"

Symbol	Run #	Structure	Box #	Slot Thickness	Slot Position	Y	Z	D
⊙	1376	III	1	0	0	2.64	18.3	Fission-a
⊗	1388	"	"	1/8	"	0	"	"
△	1407A	"	"	1/4	"	"	"	"
×	1390	"	"	1/2	"	"	"	"

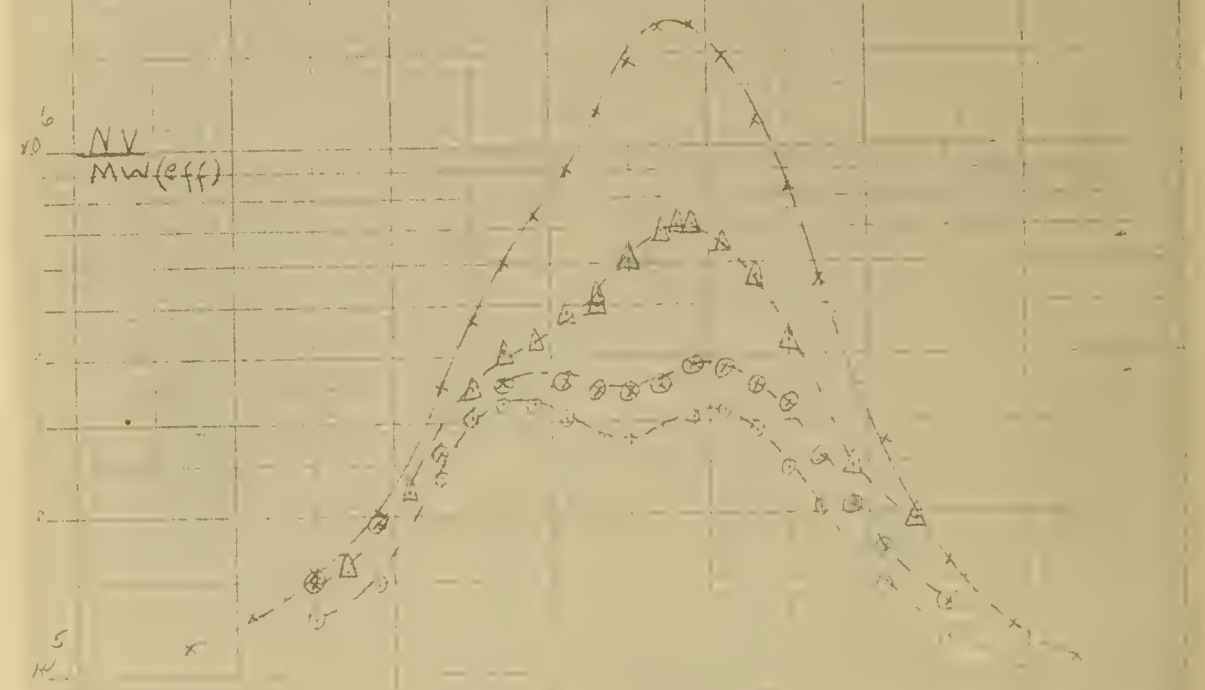
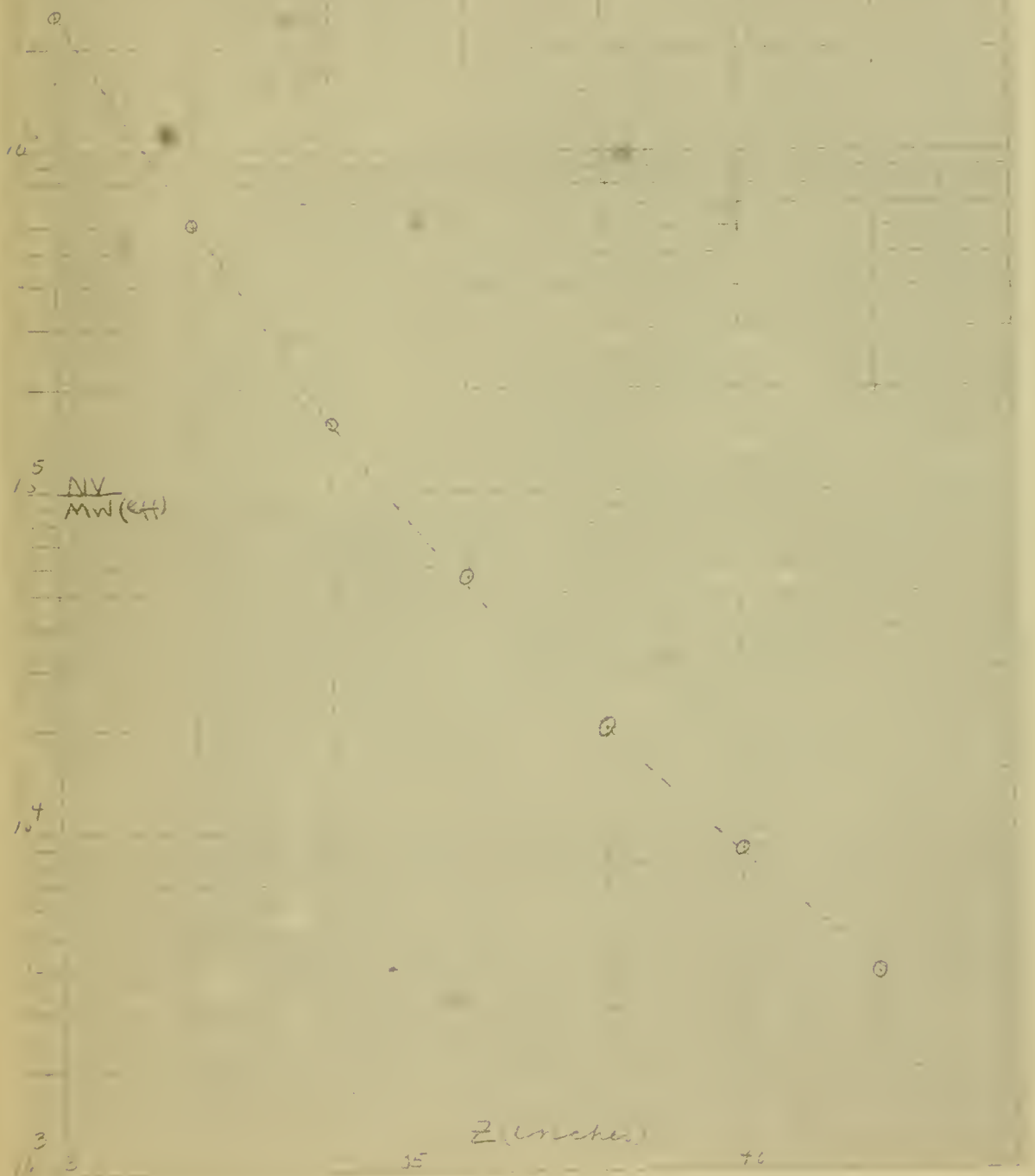


FIG 8

LENGTH = 24" WIDTH = 12"

Symbol	Run #	Structure	Box #	Slot Thickness	Slot Position	X	Y	D
C	2164	III	1,A	.3"	0	0	0	Fission

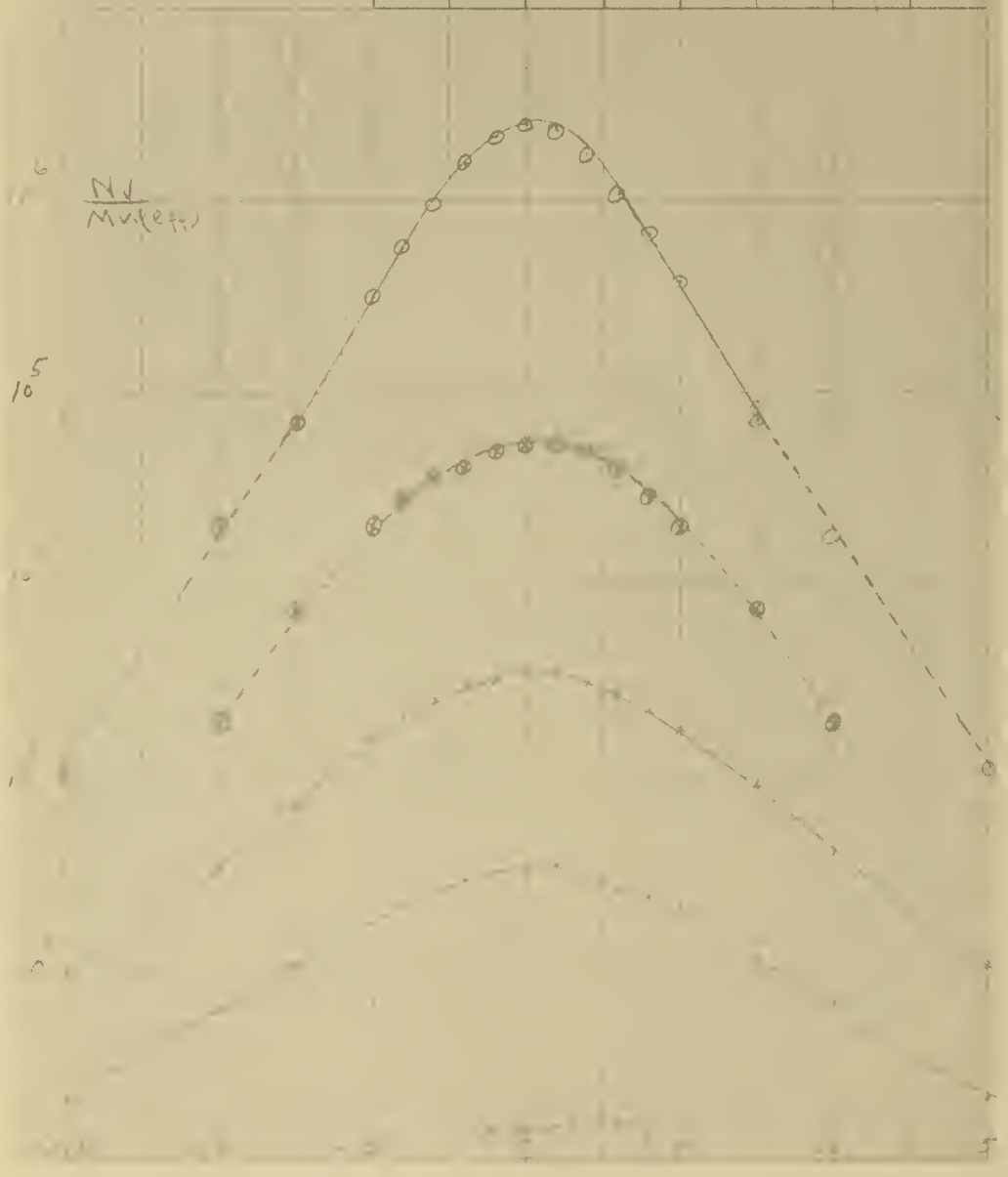


MODEL

DATE

Length = 24" Width = 12"

Sym Bol	Run #	Structure	Box #	Slot Thickness	Slot Position	Z	Y	D
⊙	2163	III	1, A	3	○	30		Fission a
⊗	2165	"	"	"		36		
×	2172	"		"	"	42		$B''F_3$
•	2173	"		"	"	48		"



Length = 24" Width = 34"

Sym Bol	Run #	Structure	Box #	Slot Thickness	Slot Position	X	Y	D
○	2538	Tii	4	0 *	0	1.5	0	Fissioning
△	2589	"	1, A	1/8	"	0	"	$B^{10}F_3$
×	2590A	"	"	1/8 **	"	"	"	"
⊗	1416	"	4	5/8	"	1.5	"	Fissioning
·	1723	"	"	"	"	1.63	"	"
□	1405A	"	"	1	"	~0.5	"	"
▽	1963	"	1, A	1.5	"	1	"	"
⊠	1424	"	4	3	"	0.5	"	"
⊠	1645	"	4	0 xxx	"	0	"	IIC

* completely filled H_2O

** 1/8" Slot in Lucite filled H_2O

xxx Normalized To 2538

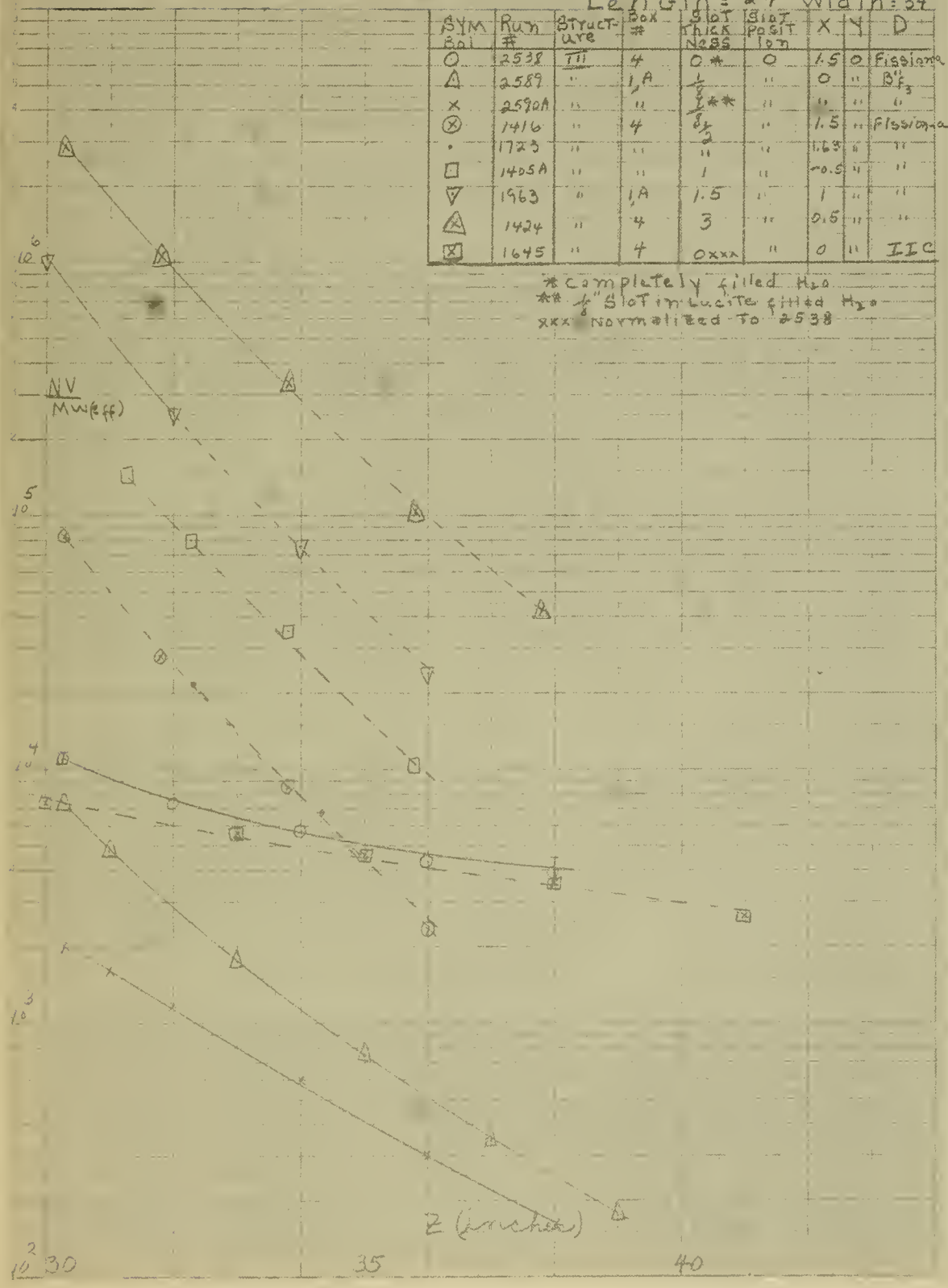


FIG. 11

Length = 24" Width = 34"

Symbol	Run #	Structure	Box #	Slot Thickness	Slot Position	Z	Y	D
⊙	1385	III	4	0	0	29.8	0	Fission a
X	2588	"	1,A	1/8	"	30.3		B"F3
⊗	2590	"	"	0*	"	"		"
△	1414	"	4	1/2	"	"		Fission a
•	1722	"	"	"	"	"		"
⊡	1404	"	"	1	"	"		"
⊠	1962	"	1,A	1 1/2	"	30*		"
▽	1422	"	4	3	"	30.3		"

*Normalized To 30.3
*1/8" slot in Lucite filled H_2O

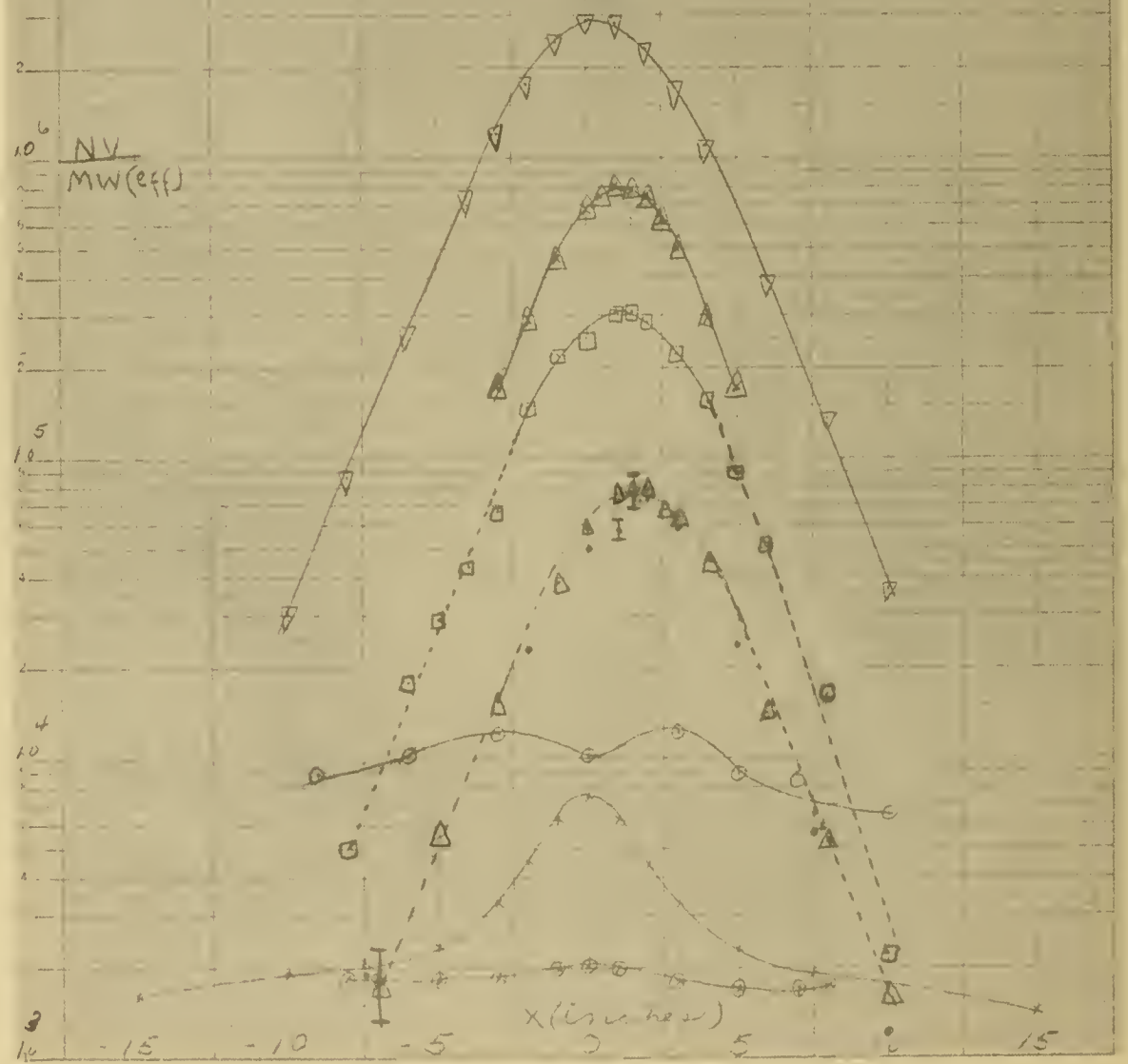
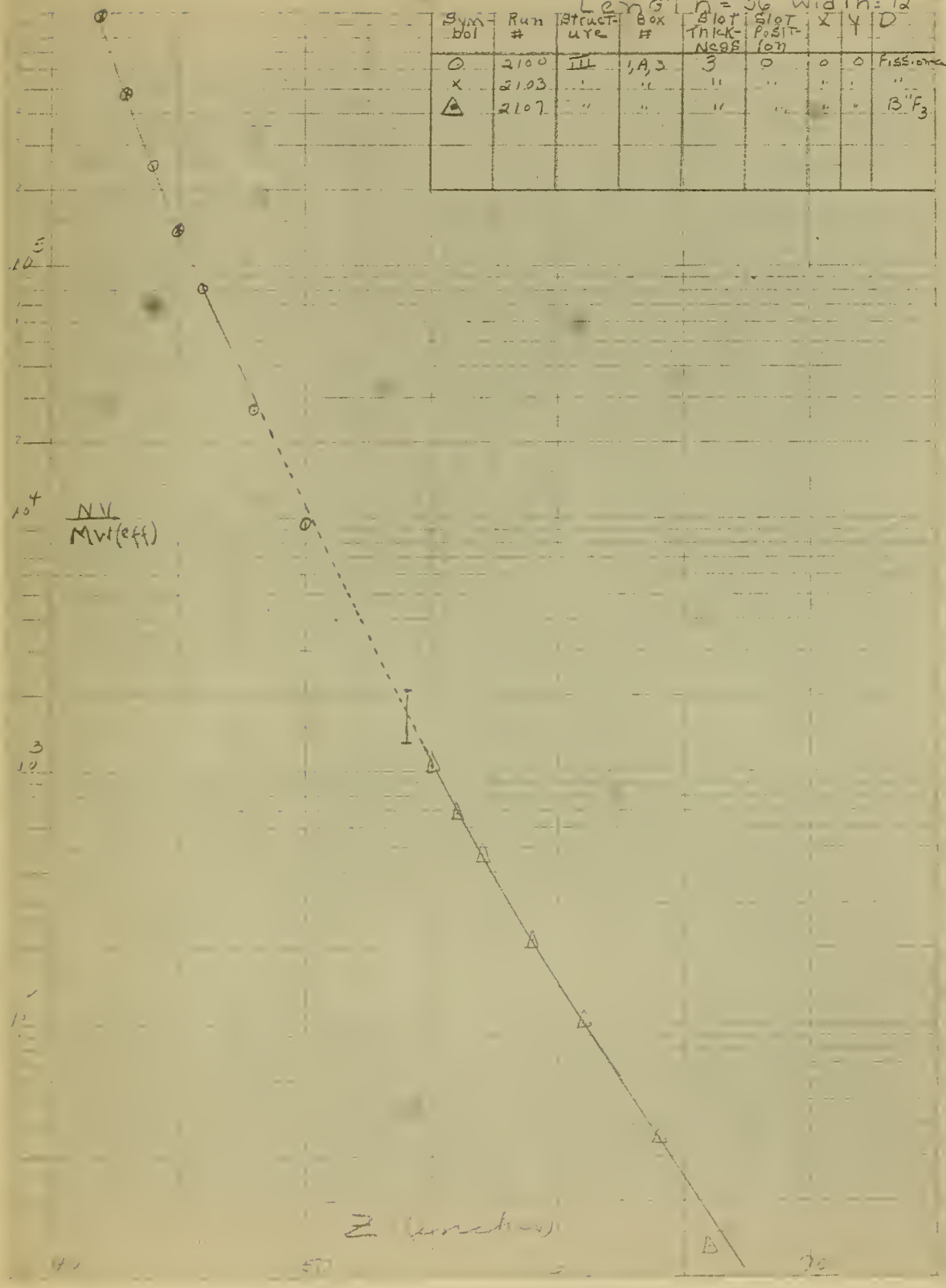


FIG. 1

Length = 36 Width = 12

Symbol	Run #	Structure	Box #	Slot Thickness	Slot Position	X	Y	D
○	2100	III	1, A, 2	3	0	0	0	Fission Chamber
×	2103	"	"	"	"	"	"	"
△	2107	"	"	"	"	"	"	$B^{10}F_3$



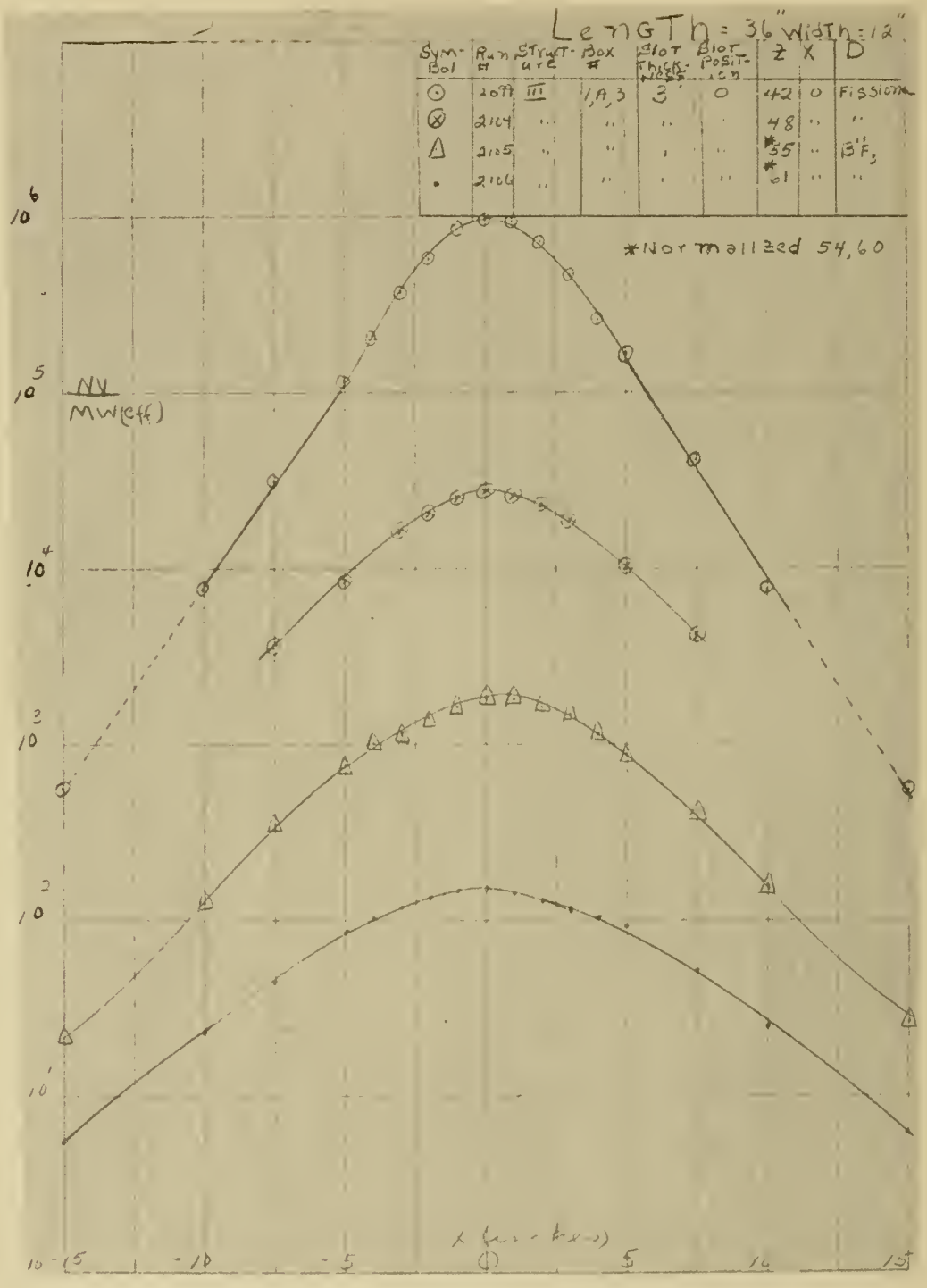
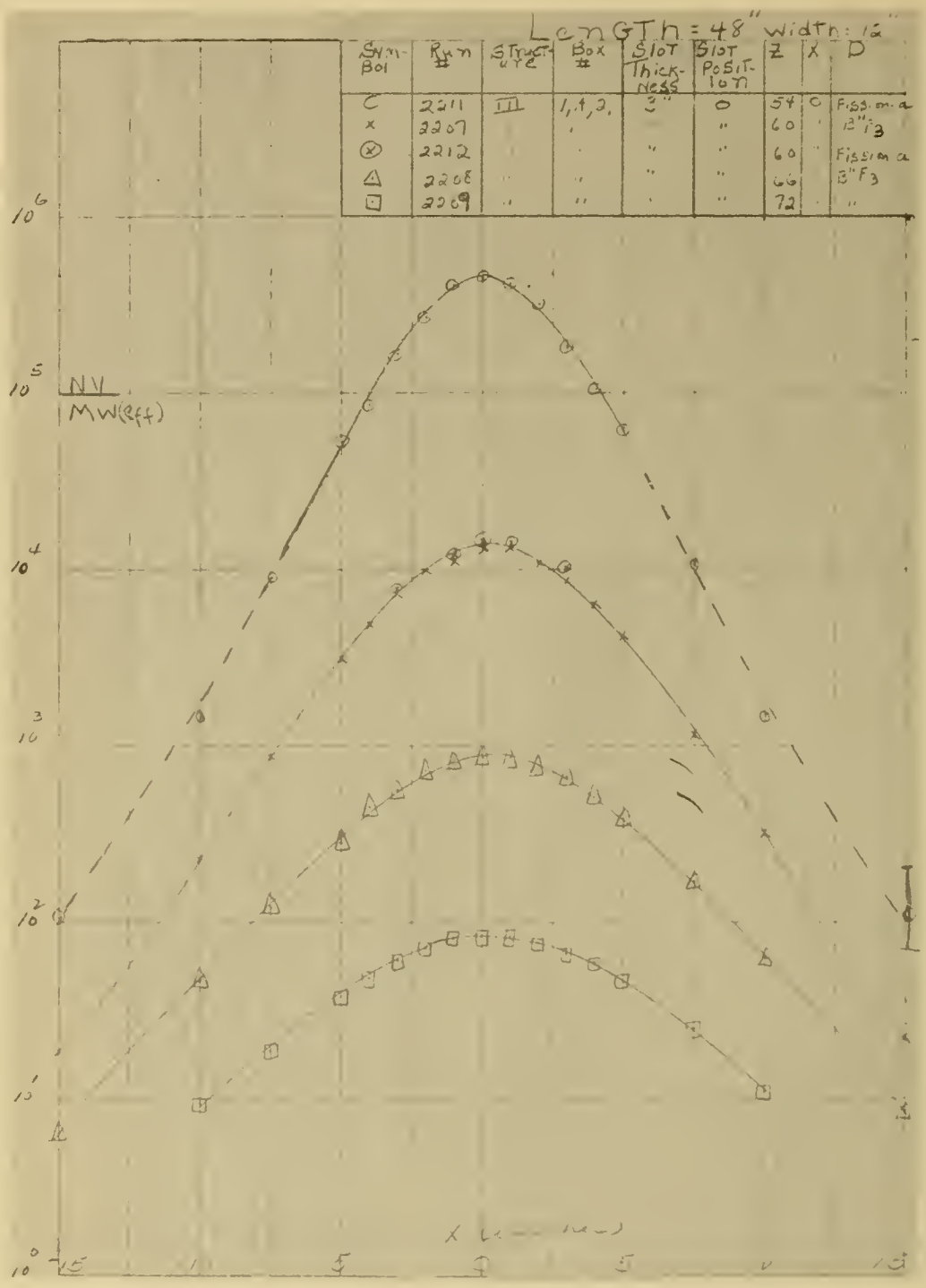

Length = 36" Width = 12"
Sym-Bol | Run # | Struct-ure | Box # | Biot Thick-ness | Biot Posit-ion | Z | X | D
⊙ | 2077 | III | 1,A,3 | 3" | 0 | 42 | 0 | Fission
⊗ | 2104 | " | " | " | " | 48 | " | "
Δ | 2105 | " | " | " | " | *55 | " | B'F3
• | 2106 | " | " | " | " | *61 | " | "
*Normalized 54,60
NV
MW(cft)
10^6
10^5
10^4
10^3
10^2
10^1
10^0
-15
-10
-5
0
5
10
15

FIG. 14

Length = 48" Width = 12"
Sym-Bol
Run #
Structure
Box #
B/oT Thick-ness
B/oT Posit-ion
X
Y
D
⊙ 2806 III 1,A,2 .3" 6 0 0 $B^{10}F_3$
⊗ 2213 " " 0 0 0 Fission-a
10^6
10^5
10^4
10^3
10^2
10^1
10^0
NV / MW(eff)
Z (inches)
50
60
70
80

FIG 15


LENGTH = 48" WIDTH = 12"
Sym-Bol | Run # | Structure | Box # | Slot Thickness | Slot Position | Z | X | D
○ | 2211 | III | 1,1,2, | 3" | 0 | 54 | 0 | Fission a
× | 2207 | " | " | " | " | 60 | " | B"F3
⊗ | 2212 | " | " | " | " | 60 | " | Fission a
△ | 2208 | " | " | " | " | 66 | " | B"F3
□ | 2209 | " | " | " | " | 72 | " | "
10^6
10^5
NV
MW(Eff)
10^4
10^3
10^2
10^1
10^0
X (inches)

F 6 16

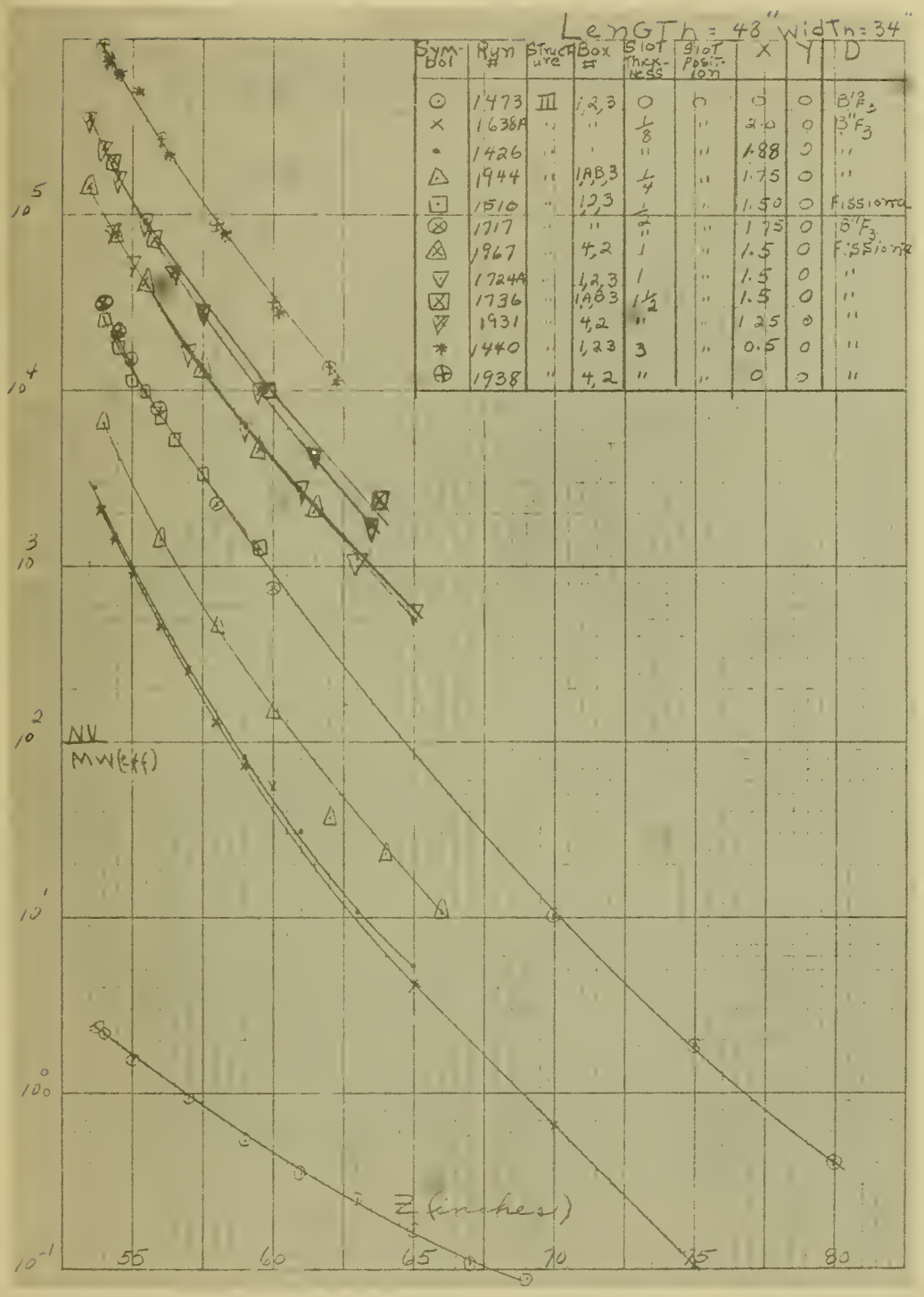

LENGTH = 48" WIDTH = 34"
Symbol | Run # | Structure | Box # | Slot Thickness | Slot Position | X | Y | D
⊙ | 1473 | III | 1,2,3 | 0 | " | 0 | 0 | B'F3
× | 1638A | " | " | 1/8 | " | 2.0 | 0 | B"F3
• | 1426 | " | " | " | " | 1.88 | 0 | "
△ | 1944 | " | 1A,B,3 | 1/4 | " | 1.75 | 0 | "
⊡ | 1510 | " | 1,2,3 | 1/2 | " | 1.50 | 0 | Fission rod
⊗ | 1717 | " | " | " | " | 1.75 | 0 | B'F3
⧋ | 1967 | " | 4,2 | 1 | " | 1.5 | 0 | Fission rod
▽ | 1724A | " | 1,2,3 | 1 | " | 1.5 | 0 | "
⊠ | 1736 | " | 1A,B,3 | 1 1/2 | " | 1.5 | 0 | "
⩛ | 1931 | " | 4,2 | " | " | 1.25 | 0 | "
* | 1440 | " | 1,2,3 | 3 | " | 0.5 | 0 | "
⊕ | 1938 | " | 4,2 | " | " | 0 | 0 | "
10^5
10^4
10^3
10^2
NW
MW(eff)
10^1
10^0
10^-1
Z (inches)
55
60
65
70
75
80

FIG. 17

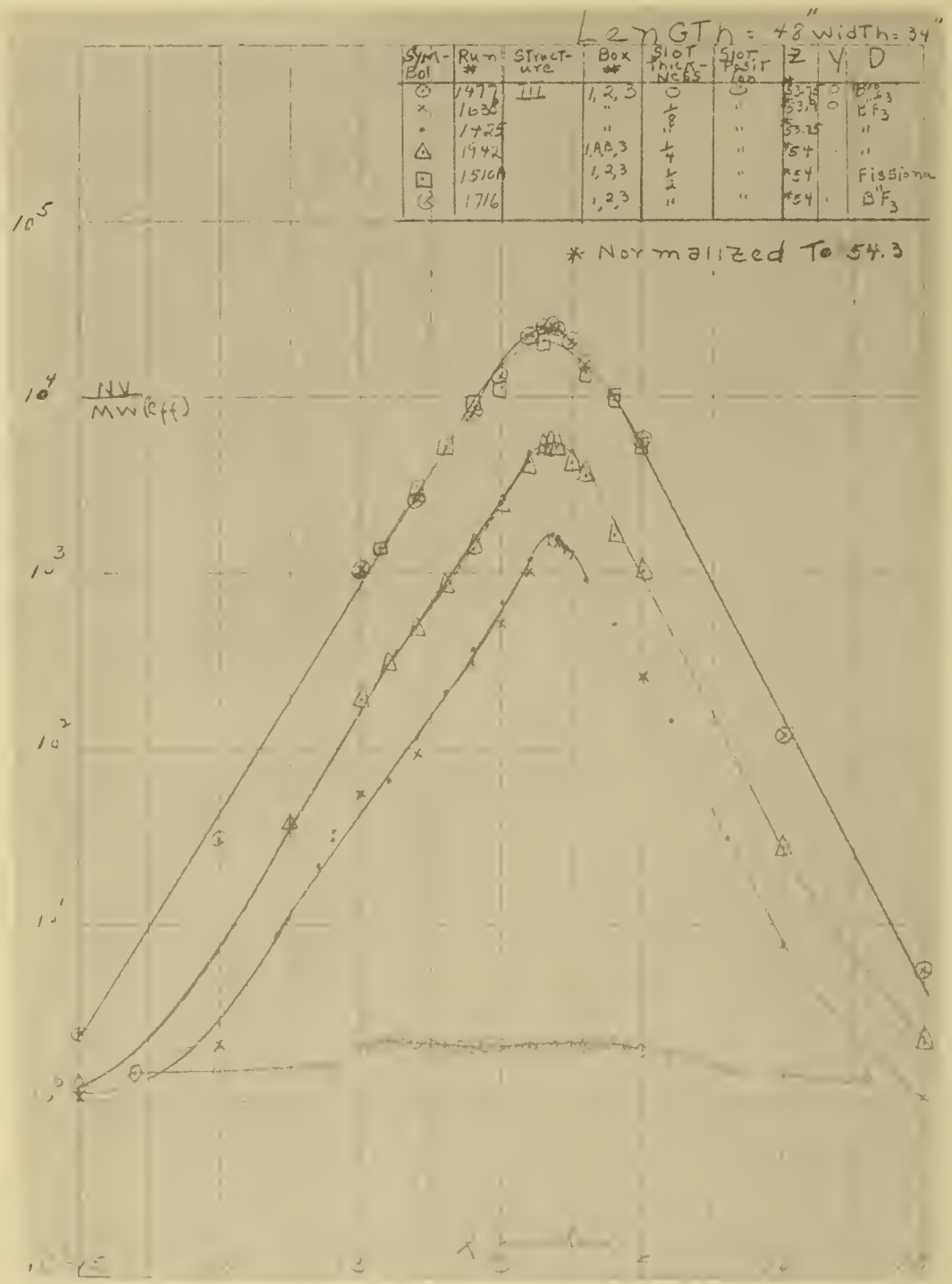

Length = 48" Width = 34"
Sym-Bol | Run # | Structure | Box # | Slot Thickness | Slot Position | Z | Y | D
⊙ | 1477 | III | 1, 2, 3 | ○ | ○ | *53.75 | ○ | B"F3
× | 1638 | | " | 1/8 | " | *53.9 | ○ | B"F3
• | 1425 | | " | " | " | *53.25 | | "
△ | 1942 | | 1, A, B, 3 | 1/4 | " | *54 | | "
⊡ | 1510A | | 1, 2, 3 | 1/2 | " | *54 | | Fissiona
⊗ | 1716 | | 1, 2, 3 | " | " | *54 | | B"F3
* Normalized To 54.3
10^5
10^4
NV / MW(eff)
10^3
10^2
10^1
10^0

Fig. 15

Length = 48" Width = 34"

Sym-bol	Run #	Structure	Box #	Slot Thickness	Slot Position	Z	Y	D
⊙	1966	III	4,2	1	0	*53.90	0	Fissioned
×	1724	"	1,2,3	1	"	54.3	"	"
⊗	1735	"	1,A,B,3	1½	"	54.3	"	"
△	1930	"	4,2	"	"	*53.9	"	"
□	1438	"	1,2,3	3	"	54.3	"	"
▽	1936	"	4,2	"	"	*54	"	"

*Normalized To 54.3

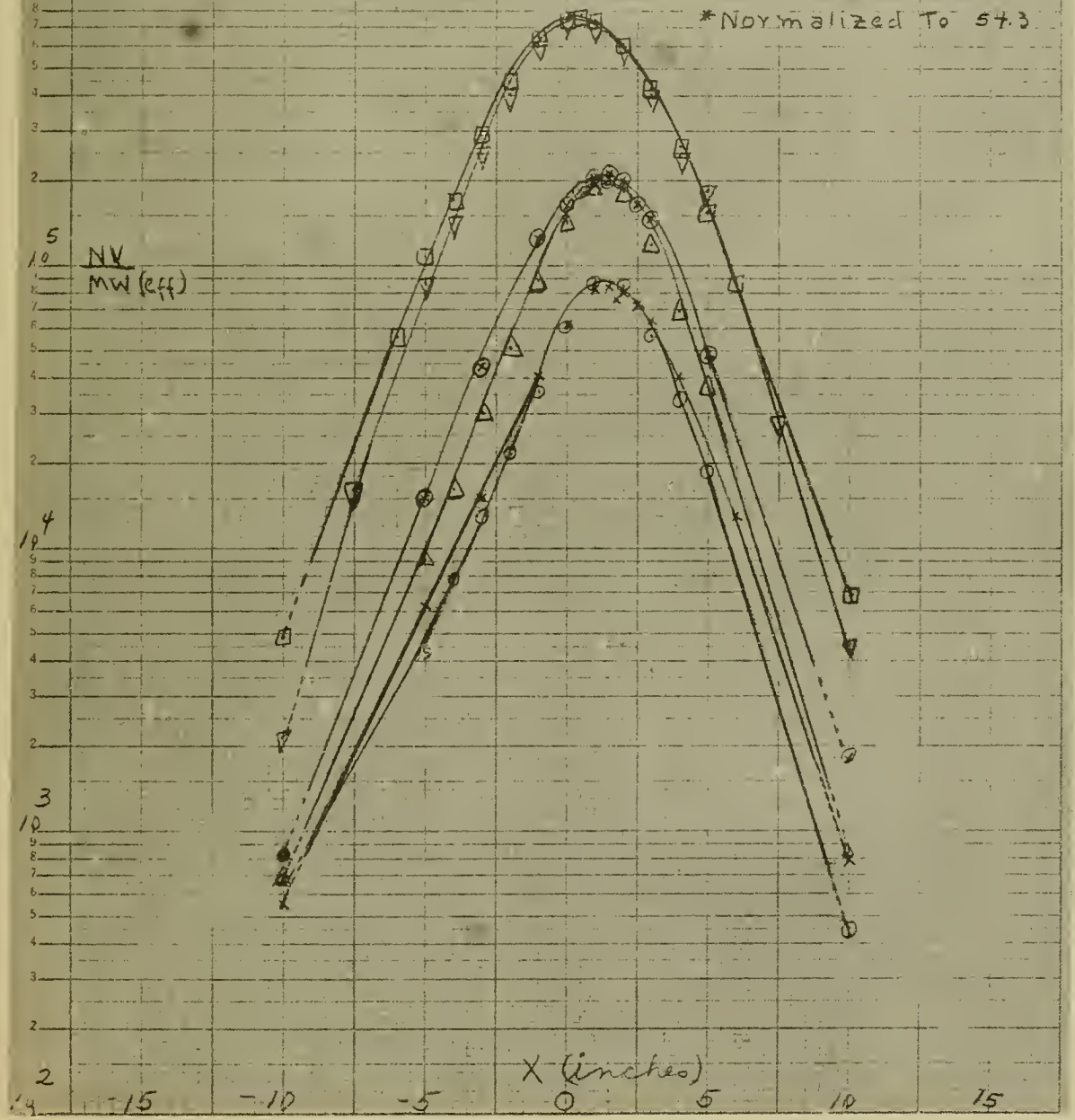
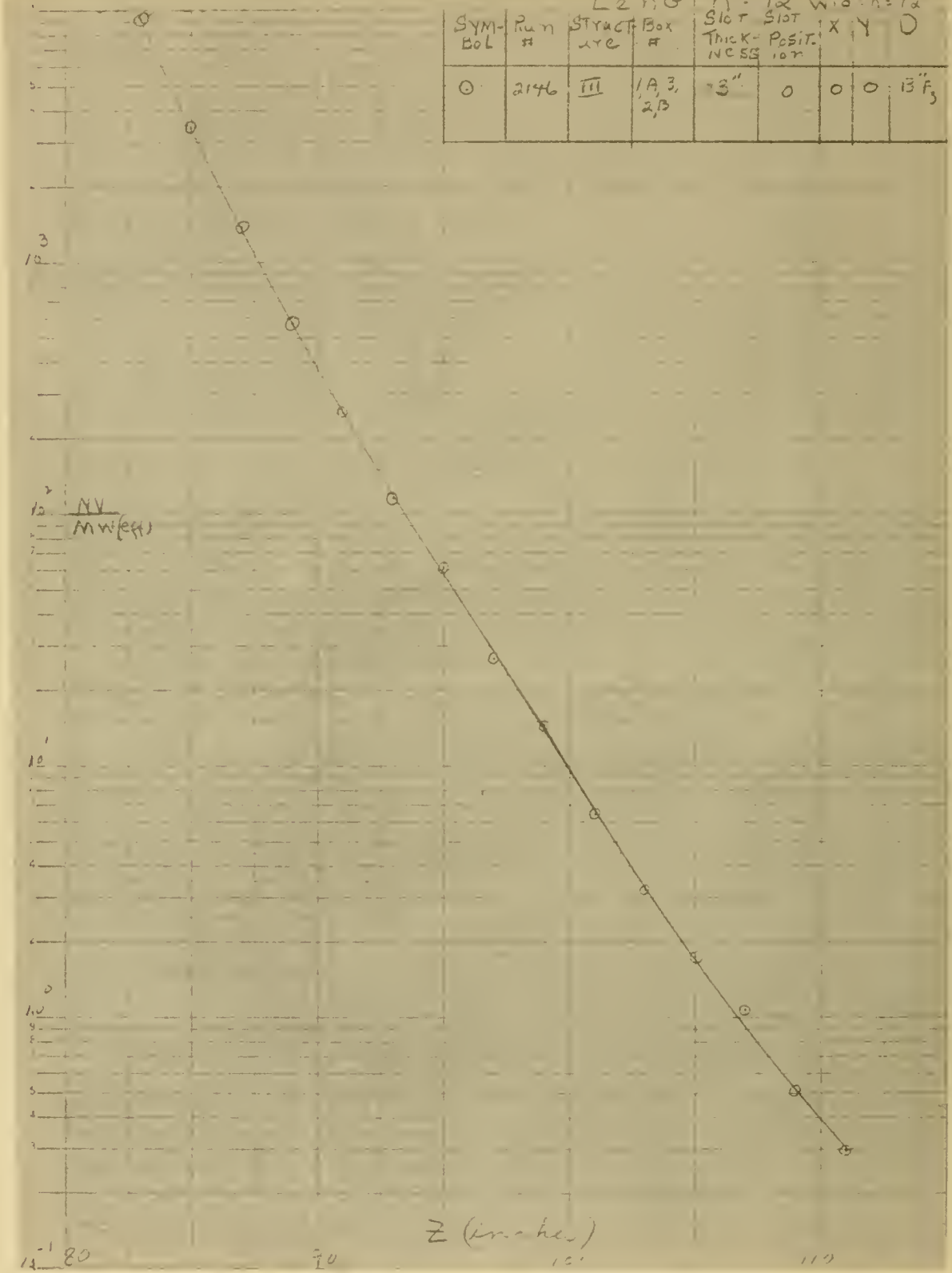


FIG. 19

Length: 72 Width: 12"

SYMBOL	Run #	STRUCTURE	Box #	Slot Thickness	Slot Position	X	Y	D
⊙	2146	III	1A, 3, 2B	.3"	0	0	0	13" F_3



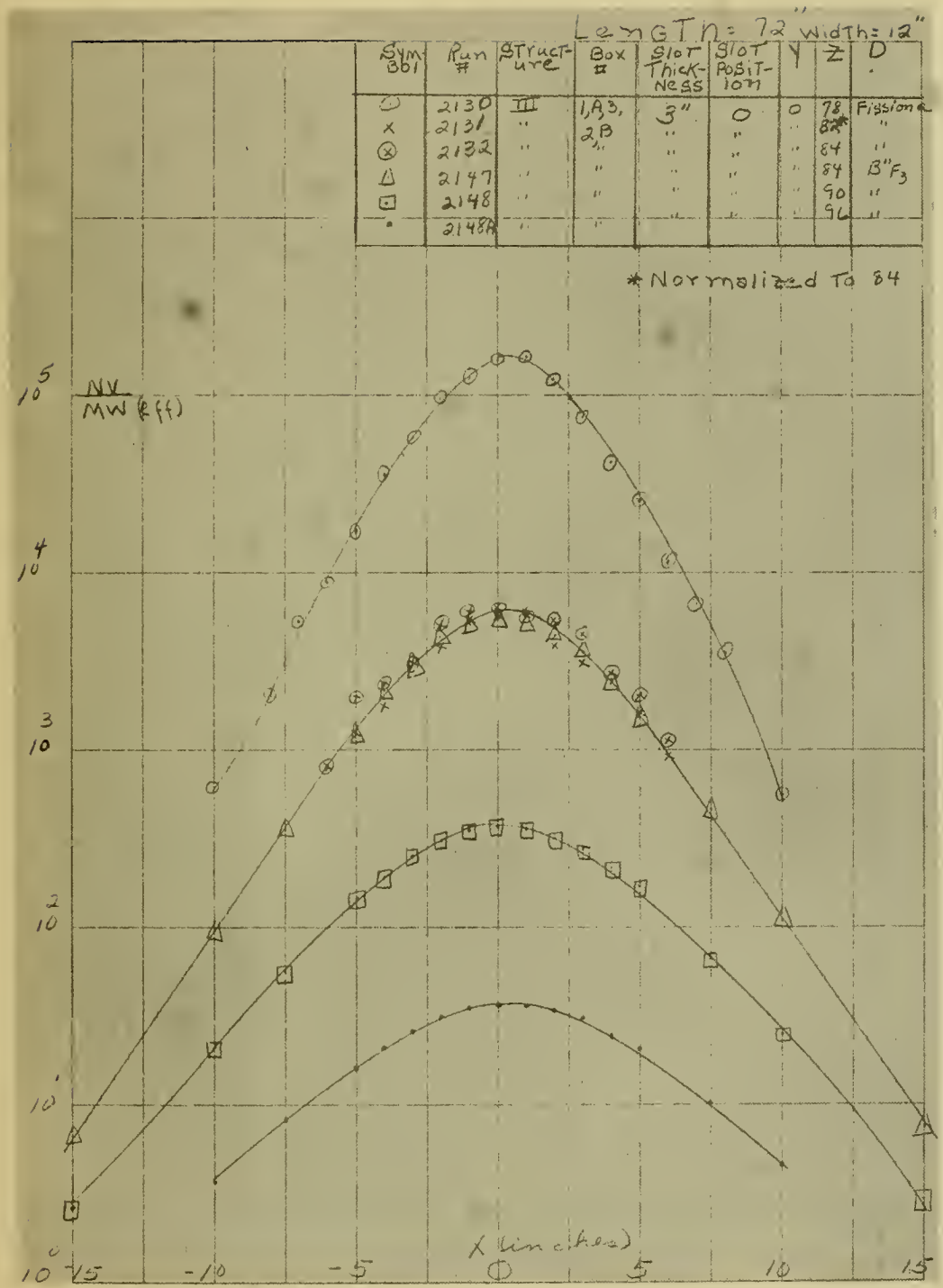

Length = 72" Width = 12"
Sym Bol | Run # | Structure | Box # | Slot Thickness | Slot Position | Y | Z | D
2130 | III | 1,A3, | 3" | 0 | 0 | 78 | Fission
2131 | " | 2,B | " | " | " | 84* | "
2132 | " | " | " | " | " | 84 | "
2147 | " | " | " | " | " | 84 | B"F3
2148 | " | " | " | " | " | 90 | "
2148A | " | " | " | " | " | 96 | "
*Normalized To 84
NV / MW (fff)
10^5
10^4
10^3
10^2
10^1
10^0
-15
-10
-5
0
5
10
15
X (inches)

FIG 21

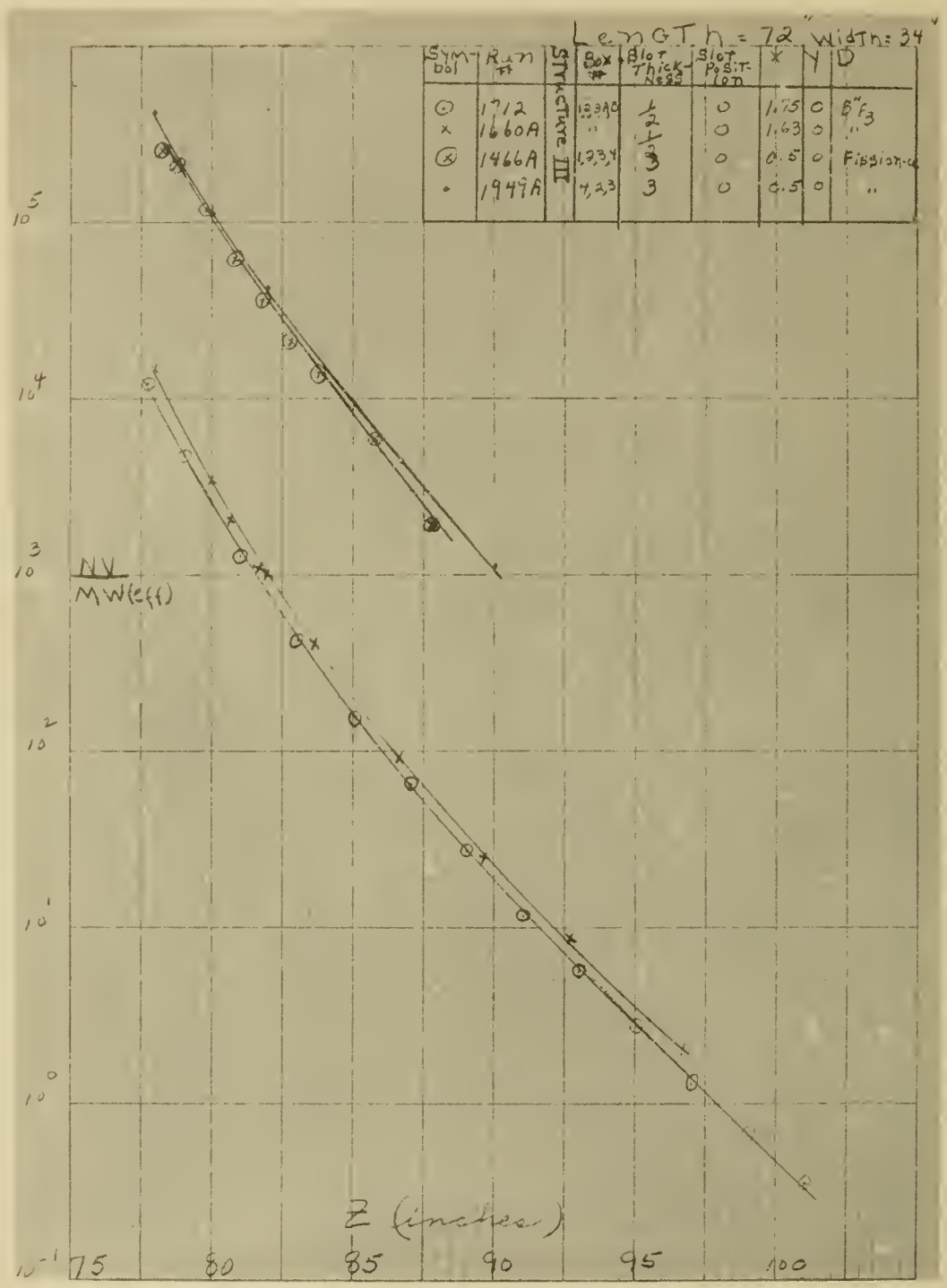

Length = 72" Width = 34"
Symbol
Run #
Structure III
Box #
Slot Thickness
Slot Position
*
Y
D
⊙ 1712 1.3990 1/2 0 1.75 0 B"F3
× 1660A " 1/3 0 1.63 0 "
⊗ 1466A 1.934 3 0 0.5 0 Fission-c
• 1949A 4.33 3 0 0.5 0 "
NV
MW(eff)
Z (inches)
10^5
10^4
10^3
10^2
10^1
10^0
10^-1
75
80
85
90
95
100

FIG. 22

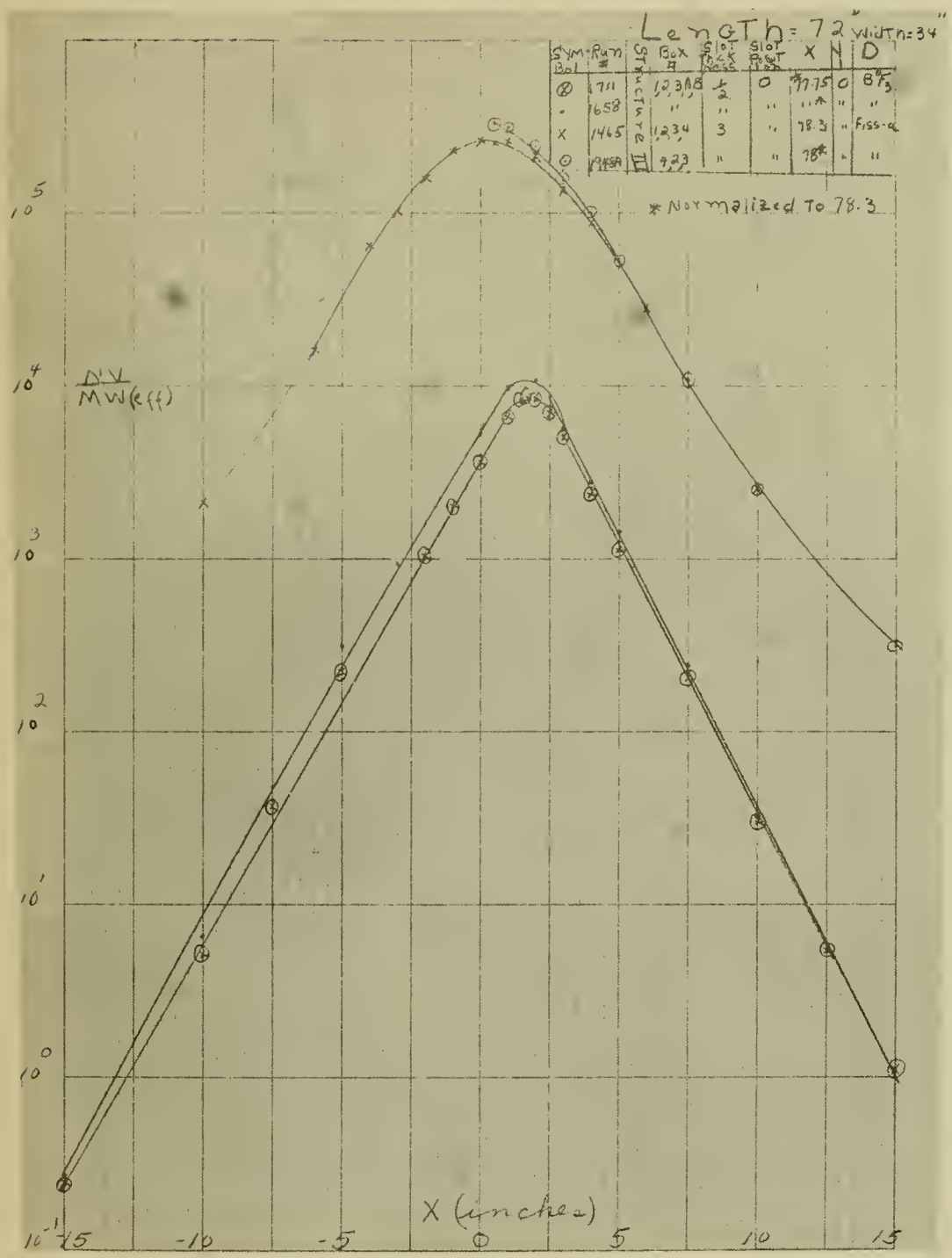

Length = 72" Width = 34"
Sym Bol | Run # | Stack | Box | Slot Back | Slot Bot | X | N | D
⊗ | 711 | Center | 1,2,3AB | ½ | 0 | 77.75 | 0 | $B^{10}F_3$
- | 1658 | " | " | " | " | " | " | "
X | 1465 | Tyr | 1,2,3,4 | 3 | " | 78.3 | " | Fiss-α
⊙ | 1458 | " | 4,2,3 | " | " | 78* | " | "
* Normalized To 78.3
C2
$\frac{\Delta V}{MW(eff)}$
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
-15
-10
-5
0
5
10
15
X (inches)

FIG. 23

Length = 96 Width = 34"

Symbol	Run #	Structure	Box #	Right Thick.	Slot Pos.	X	Y	D
⊙	1707	III	1233A B,4	7/8	0	1.75	0	B"F3

NW
MW(Cff)

Z (inches)

100 110 120

FIG. 24

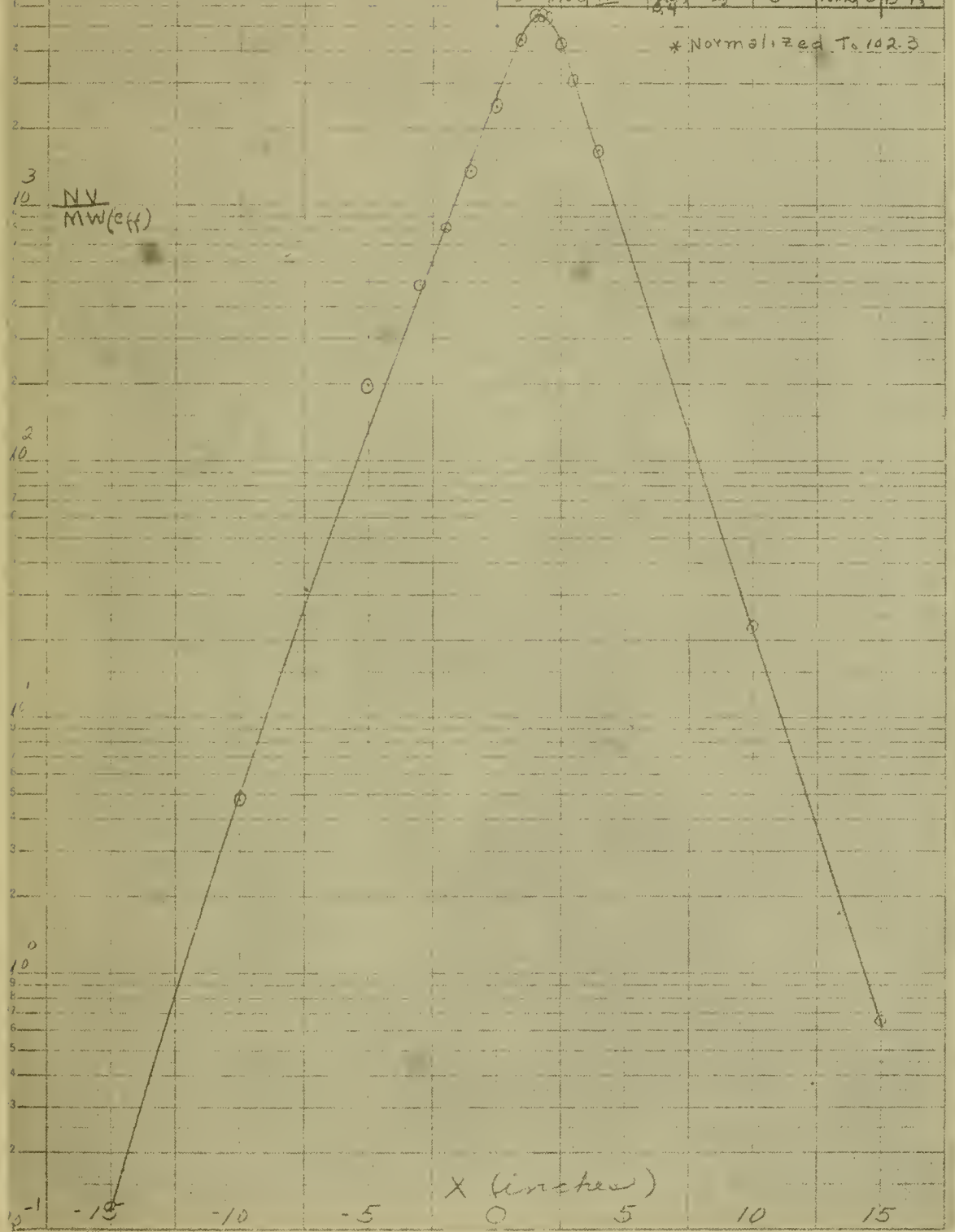


FIG 25

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